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Inventor(s): Michael J. DeBar

Zhihao Yang

Attorney: Raymond L. Owens

MEASURING ABSOLUTE STATIC PRESSURE AT ONE OR MORE POSITIONS ALONG A MICROFLUIDIC DEVICE

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MEASURING ABSOLUTE STATIC PRESSURE AT ONE OR MORE POSITIONS ALONG A MICROFLUIDIC DEVICE

FIELD OF THE INVENTION

The present invention relates to measuring the absolute static

5   pressure of fluid flowing in a microfluidic device.

BACKGROUND OF THE INVENTION

Conducting of fluid in microfluidic devices is frequently done in inkjet printers. It is also done in other types of microfluidic devices in fields not related to printing, for example, drug delivery and microscale biological and

10   chemical analysis. In the inkjet printing field, ink is transported from a reservoir to a printhead, where it is sprayed onto print media. If a nozzle becomes clogged, the absolute static pressure within the relevant ejection chamber may exceed normal values. Thus, absolute static pressure detection can be used as a nozzle-by-nozzle diagnostic tool in the case of an inkjet printer. Similarly, absolute static

15   pressure sensing in drug delivery systems is critical due to the potential hazards of inaccurate dosing. In microscale biological and chemical analysis systems, where precision is critical, an integrated absolute static pressure sensor reduces the error associated with sensing the absolute static pressure across an intervening volume between the microfluidic device and a non-integrated sensor; in addition, an

20   integrated pressure sensor reduces the volume of fluid that must be sacrificed to measure the pressure. This increases cost and waste, and in the case of biological analysis systems, for example, it increases the required sample size, making sample collection and preparation more difficult and costly.

While prior art exists for pressure drop measurement across

25   microfluidic and macrofluidic systems, even microscale measurement systems are integrated on the macroscale, allowing measurement of absolute static pressure as the working fluid enters or exits a microfluidic device, but not while the working fluid is within the interior of the microfluidic device. For example, U.S. Patent No. 4,426,768 teaches the use of the measurement of a strain-dependent property

30   to deduce the local absolute pressure of a non-conductive fluid. Similarly, U.S. Patent No. 4,463,336 teaches the measurement of absolute gas pressure using the

varying resistance of a narrow piezoresistive bridge. Electrically conductive liquids cannot be measured with this sensor. U.S. Patent No. 4,682,503 teaches the use of measuring the varying thermal resistance of a silicon nitride bridge to the same end. This sensor does not work with an electrically conducting fluid,

5 and struggles to provide accurate data with a fluid of high heat capacity. A number of sensors measuring pressure via the capacitance between a deforming membrane and a fixed electrode have been previously disclosed. U.S. Patent Nos. 5,305,643; 5,316,619; 5,369,544 and 6,109,113 teach the measurement of absolute pressure against a standard (normally vacuum or the ambient atmosphere) by

10 capacitance, while U.S. Patent Nos. 5,332,469; 5,679,902 and 6,012,335 teach the use of capacitance to measure the relative difference of two varying pressures. In all cases, the region across which the field is applied must not be penetrated by any fluid with a different dielectric constant from that of the fluid originally between the two plates. U.S. Patent No. 5,458,000 teaches the use of a second

15 resonant sensor that is not affected by changes in pressure but responds to changes in temperature for use in temperature error compensation. This sensor will not operate in a viscous fluid. U.S. Patent Nos. 5,528,939 and 5,939,635 teach the measurement of energy needed to move a resonant member near a stationary surface, where the damping losses are highly pressure dependent. This can only

20 be used to measure a compressible working fluid, however, or the variation in damping force will not be evident. U.S. Patent No. 5,808,210 teaches measurement of absolute pressure by measuring deformation either electrically or optically. While this sensor can be used for optical measurement of the membrane deflection, it cannot be used with an opaque working fluid.

25 U.S. Patent No. 6,575,026 teaches the use of an integrated absolute static pressure sensor on a microchannel to measure absolute static pressures and flow rates, but requires optical interrogation of a visual scale for pressure determination. This process may be expensive to implement in an automated system due to the optical equipment required to observe such small features. In

30 addition, if image analysis is necessary, computational power needs (and costs) may be substantial.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved way to measure the absolute static pressure in a microfluidic device transporting a working fluid.

This object is achieved in a method of measuring absolute static pressure at one or more positions along the wall of a microfluidic device transporting a working fluid that is immiscible in a first selected gas environment, comprising:

(a) providing a first fluid conducting channel having an atmosphere provided by the first selected gas environment in a sealed environment and in communication with the microfluidic device at a first point of communication;

(b) providing a first sensing mechanism that is electrically interrogated, disposed adjacent to the first fluid conducting channel; and

(c) transporting the working fluid under pressure conducted by the microfluidic device into the first fluid conducting channel such that the volume transported into such first fluid conducting channel varies depending upon the absolute static pressure of the working fluid at the first point of communication, whereby the absolute static pressure at the first point of communication is electrically determined by the first sensing mechanism depending on the position of the interface of the working fluid and the first selected gas environment in the first fluid conducting channel.

It is an advantage of the present invention to output an electrical signal directly related to the volume in a first fluid conducting channel in communication with the microfluidic device to readily determine the absolute static pressure in the first fluid conducting channel without the need for moving parts.

It is a further advantage of the present invention to measure absolute static pressure over a variety of pressure ranges at the same point of communication, thereby increasing the effective absolute static pressure range of the sensor.

It is a further advantage of the present invention to measure absolute static pressure at a precise location within a microfluidic device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a schematic of an ink jet printing apparatus that has a microfluidic device in which the present invention is adapted to measure the absolute static pressure therein;

FIG. 2 is a schematic of a first embodiment of the present invention;

FIG. 3 is a schematic of a second embodiment of the present invention; and

FIG. 4 is a schematic of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The term, "microfluidic", "microscale" or "microfabricated" generally refers to structural elements or features of a device, such as fluid channels, chambers or conduits, having at least one fabricated dimension in the range from about 0.1 μm to about 500 μm. In devices according to the present invention, the microscale channels or chambers preferably have at least one internal cross-section dimension, e.g., depth, width, length, diameter, etc., between about 0.1 μm to about 500 μm, preferably between about 1 μm to about 200 μm.

The microfluidic devices described in the present invention are preferably fabricated with the techniques commonly associated with the semiconductor electronics industry, e.g., photolithography, dry plasma etching, wet chemical etching, etc., on the surface of a suitable substrate material, such as silicon, glass, quartz, ceramics, as well as polymeric substrates, e.g., plastics.

Various techniques using chip technology for the fabrication of microfluidic devices, and particularly micro-capillary devices, with silicon and glass substrates have been discussed by Manz, et al. (*Trends in Anal. Chem.* 1990, *10*, 144, and *Adv. In Chromatog.* 1993, *33*, 1). Other techniques such as laser ablation, air abrasion, injection molding, embossing, etc., are also known to be

used to fabricate microfluidic devices, assuming compatibility with the selected substrate materials.

The present invention uses a method of measuring absolute static pressure at one or more positions along the wall of a microfluidic device transporting a working fluid that is immiscible in a first selected gas environment, comprising the steps of: providing a first fluid conducting channel having an atmosphere provided by the first selected gas under a sealed environment and in communication with the microfluidic device at a first point of communication; providing a first sensing mechanism that is electrically interrogated, disposed adjacent to the first fluid conducting channel; and transporting the working fluid under pressure conducted by the microfluidic device into the first fluid conducting channel such that the volume transported into such first fluid conducting channel varies depending upon the absolute static pressure of the working fluid at the first point of communication, whereby the absolute static pressure at the first point of communication is electrically determined from the first sensing mechanism depending on the position of the interface of the working fluid and the first selected gas environment in the first fluid conducting channel. If the volume occupied by the first selected gas environment is known at static conditions and the absolute static pressure is known under ambient conditions, then the absolute static pressure during operation is determined by the motion of the interface between the working fluid and the first selected gas environment, using, for example, the ideal gas law,

$$PV = nRT \, ,$$

where P represents the absolute static pressure of the first selected gas environment, which is presumed to be related in a known way to the absolute static pressure of the working fluid at the first point of communication, V represents the volume occupied by the first selected gas environment, n represents the number of moles of gas in the first selected gas environment, R represents a universal gas constant, and T represents the absolute temperature of the first selected gas environment. For steady-state working fluid/selected gas environments, the following relation applies:

$$P_{fluid} = P_{gas} - \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\cos\theta$$

where P_{fluid} is the absolute static pressure of the working fluid at the point of communication; P_{gas} is the absolute static pressure of the first selected gas environment; R_1 and R_2 are the local radii of curvature of the interface between

5   the first selected gas environment and the working fluid; θ is the contact angle of the three-phase system formed by the working fluid, the first selected gas environment, and the wall of the microfluidic device; and σ is the surface tension of the three-phase system described above. In cases where the surface tension is very small, $(\sigma \to 0)$, the absolute static pressure of the working fluid may be

10   considered equal to the absolute static pressure of the selected gas environment. Hence, the present invention can measure absolute static pressure at a precise location within a microfluidic device.

More complex models that relate absolute static pressure, volume, and temperature to physical constants can also be used to improve accuracy. For

15   example, the additional terms in the van der Waals or "real gas" equation (shown below) will improve accuracy for cases where a higher density of gas molecules causes stronger intermolecular interaction.

$$\left(P + \frac{C_1}{V^2}\right)(V - C_2) = nRT$$

In this equation the two additional constants C_1 and C_2 are determined by the

20   type of gas in the first selected gas environment.

Turning now to FIG. 1, a schematic diagram is shown of a printing apparatus 10 including at least one ink reservoir 12, drive electronics 14, and a plurality of individually addressable printheads 16 in communication with both the ink reservoirs 12 and the drive electronics 14. Ink is introduced into each

25   individually addressable printhead 16 by means of a microfluidic device 18, in this case a microfluidic channel, which in turn is in communication with an absolute static pressure sensor 20. A computer 22 receives or generates data 24 representing, for example, a digital image. The computer 22 also controls the

output to the printing apparatus 10 by means of electrical signals to the drive electronics 14. The drive electronics 14 in turn control a transport mechanism 26, which conveys a receiver 28 to the individually addressable printheads 16 so that ink pixels may be transferred to the receiver 28. The ink flow may be controlled by any means including but not limited to thermal ejection, piezoelectric ejection, or electrostatic ejection. The computer 22 also controls the individually addressable printheads 16.

FIG. 2 depicts a first embodiment of the absolute static pressure sensor 20 shown in FIG. 1, that measures absolute static pressure in a working fluid 30 at the first point of communication 32 of a first fluid conducting channel 34 with the microfluidic device 18. The working fluid 30 may be, but is not limited to any of the following fluids: water, ink, ethylene glycol, methanol, ethanol, isopropanol, oil, acetone, an organic solvent, a biological fluid, or a solution of a chemical analyte, or a miscible combination of these. There are no restrictions on the optical properties of the working fluid 30. The first point of communication 32 should be kept as small as possible to minimize disruption to the flow in the microfluidic device 18; however, if the first point of communication 32 is too small, the response time of the absolute static pressure sensor 20 will become large, since equilibration of the absolute static pressure sensor 20 will be limited by the rate at which the working fluid 30 can flow through the first point of communication 32.

Generally, the placement of the absolute static pressure sensor 20 is that the first point of communication 32 should be located where the local working fluid velocity during normal operation is parallel to the plane of the first point of communication 32. If the working fluid 30 can exert momentum in the direction normal to the plane of the first point of communication 32, the absolute static pressure registered by the absolute static pressure sensor 20 will not be the absolute static pressure of the working fluid 30 at the first point of communication 32, but rather the absolute stagnation pressure of the working fluid 30 at the first point of communication 32, if the local fluid velocity vector is normal to the plane of the first point of communication 32, or some intermediate value between these

two pressures if the local working fluid velocity vector impacts the plane of the first point of communication 32 at some angle between zero and ninety degrees.

In addition to the use of the present invention to measure the absolute static pressure in a microfluidic channel, the absolute static pressure sensor 20 can measure the absolute static pressure at any point in a microfluidic device 18. For example, the absolute static pressure of an ink chamber is measured by placing a first fluid conducting channel 34 in communication with the ink chamber.

When the individually addressable printhead 16 is primed with a working fluid 30 (in this case ink) before use by the drive electronics 14, the microfluidic device 18 will fill with fluid. Depending on the pressure used to prime the absolute static pressure sensor 20 and the ambient pressure conditions upon filling, a certain amount of gas will be trapped within the first fluid conducting channel 34, forming an atmosphere provided by the first selected gas environment 36 at the end of the first fluid conducting channel 34. The working fluid 30 is separated from the first selected gas environment 36 by a first interface 38. This first selected gas environment 36 includes air, nitrogen, argon, neon, helium, oxygen, hydrogen, water vapor, carbon monoxide, or carbon dioxide or a miscible combination of these. The limitations on the selected gas environment 36 are that the selected gas environment 36 must have a dielectric constant different from that of the working fluid 30, the selected gas environment 36 must be immiscible with the working fluid 30, and the selected gas environment 36 must be non-reactive in the presence of the working fluid 30. Similarly, for non-inkjet microfluidic devices, there will be an initial filling of the microfluidic device 18 generally accomplished by forcing the working fluid 30 through the microfluidic device 18 using an external pressure source. In order to use the absolute static pressure sensor 20, the initial volume of this first selected gas environment 36 must be determined by electrically interrogating the first sensing mechanism 40, disposed adjacent to the first fluid conducting channel 34, while the absolute static pressure sensor 20 is under ambient pressure. For example, if the sensing mechanism 40 were a capacitive element, its capacitance would vary

linearly (for a first fluid conducting channel 34 of constant cross-section) with the position of a first interface 38, due to the difference in dielectric constant of the working fluid 30 and the selected gas environment 36. The design of such a sensing mechanism is well known to those skilled in the art. From the position of

5   the first interface 38, the volume of the selected gas environment 36 is determined.

Using the initial volume, measured under ambient static conditions, and an equilibrium volume, subsequently measured while the microfluidic device is in operation, the operating absolute static pressure is determined. Since a fixed

10 amount of gas (on a molar basis) is trapped within the first selected gas environment 36, the following relation for the operational absolute static pressure, P_2, holds under isothermal equilibrium conditions as a direct result of the ideal gas law:

$$P_2 = P_1 \frac{V_1}{V_2}$$

15 where P_1 is the ambient absolute static pressure (measured with, for example, an external barometer) at which V_1, the initial volume, is measured and P_2 is the operational absolute static pressure at which V_2, the operational volume, is measured. In addition to this rigorous determination of absolute static pressure under isothermal equilibrium conditions, the absolute static pressure sensor 20 can

20 qualitatively determine the effectiveness of an individually addressable printhead 16 relative to its neighbors. If the first selected gas environment 36 of a certain absolute static pressure sensor 20 ceases to register changes in volume while the first selected gas environments of the absolute static pressure sensors 20 of all neighboring individually addressable printheads 16 continue to register

25 fluctuations in volume, a defective or broken individually addressable printhead 16 is detected during operation. Similarly, if the volume fluctuations of the first selected gas environment 36 in one absolute static pressure sensor 20 indicate an inordinately large absolute static pressure change in one individually addressable printhead 16, a partial or total blockage of the microfluidic device 18 may have

occurred. If one integrates electronic logic circuits that monitor the absolute static pressure in each individually addressable printhead 16, the printing apparatus 10 will have the ability to dynamically diagnose failure of certain individually addressable printheads 16 and direct the drive electronics 14 to correct for this

5   failure. These benefits extend beyond the domain of inkjet printing into other applications. For example, a microfluidic device releasing a steady dose of a drug through a microfluidic needle, a sudden drop in absolute static pressure (rise in volume) would be indicative of a blockage upstream, or a failure of the ink reservoir 12 or other pressure source driving the flow. Conversely, a rise in

10   absolute static pressure would indicate a blockage downstream, causing the entire microfluidic device 18 to equilibrate to a higher absolute static pressure, since the majority of the absolute static pressure loss would occur across the blockage.

        FIG. 3 depicts a second embodiment of the absolute static pressure sensor 20 shown in FIG. 1. Absolute static pressure is measured at multiple points

15   along the microfluidic device 18. As with the first point of communication 32, a second point of communication 42 and any additional points of communication 52 should be kept as small as possible to minimize disruption to the flow in the microfluidic device 18. However, if the second point of communication 42 or any additional point of communication 52 is too small, the response time of the

20   absolute static pressure sensor 20 will become large, since equilibration of the absolute static pressure sensor 20 will be limited by the rate at which fluid can flow through the second point of communication 42 or the additional point of communication 52, respectively. When the individually addressable printhead 16 is primed with a working fluid 30 (in this case ink) before use by the drive

25   electronics 14, the microfluidic device 18 will fill with fluid. Depending on the pressure used to prime the absolute static pressure sensor 20, and the ambient pressure conditions upon filling, a certain amount of gas will be trapped within the first fluid conducting channel 34, the second fluid conducting channel 44, and any additional fluid conducting channels 54, forming an atmosphere provided by the

30   first selected gas environment 36 at the end of the first fluid conducting channel 34, a second atmosphere provided by the second selected gas environment 46 at

the end of the second fluid conducting channel 44, and forming an additional atmosphere provided by the additional selected gas environment 56 at the ends of the additional fluid conducting channel 54. The working fluid 30 is separated from the second selected gas environment 46 by a second interface 48. Similarly, the working fluid 30 is separated from the additional selected gas environment 56 by an additional interface 58. The second selected gas environment 46 and additional selected gas environment 56 include air, nitrogen, argon, neon, helium, oxygen, hydrogen, water vapor, carbon monoxide, or carbon dioxide or a miscible combination of these.

For non-inkjet microfluidic devices, there will be an initial filling of the microfluidic device 18 generally accomplished by forcing the working fluid 30 through the microfluidic device 18 using an external pressure source. In order to use the absolute static pressure sensor 20 the initial volume of this first selected gas environment 36 must be determined by electrically interrogating the first sensing mechanism 40 while the absolute static pressure sensor 20 is under ambient pressure. Similarly, the initial volume of the second selected gas environment 46 must be determined by electrically interrogating the second sensing mechanism 50, disposed adjacent to the second fluid conducting channel 44, while the absolute static pressure sensor 20 is under ambient pressure, and the initial volume of any additional selected gas environment 56 must be determined by electrically interrogating the additional sensing mechanism 60, disposed adjacent to the additional fluid conducting channel 54, while the absolute static pressure sensor 20 is under ambient pressure.

Subsequently during microfluidic device operation, electrical interrogation of the first sensing mechanism 40 determines the volume of the first selected gas environment 36, electrical interrogation of the second sensing mechanism 50 determines the volume of the second selected gas environment 46, and electrical interrogation of the additional sensing mechanism 60 determines the volume of the additional selected gas environment 56. Using the initial volume measured under ambient static conditions and an equilibrium operational volume measured while the microfluidic device 18 is in operation, the operational absolute

static pressure is determined. Since a fixed amount of gas is trapped within each
of the selected gas environments 36, 46, and 56, the following relation holds for
each operational absolute static pressure, P_2, under isothermal equilibrium
conditions as a direct result of the ideal gas law:

5

$$P_2 = P_1 \frac{V_1}{V_2}$$

where P_1 is the ambient absolute static pressure (measured with, for example, an
external barometer) at which V_1, the initial volume, is measured and P_2 is the
operational absolute static pressure at which V_2, the operational volume, is
measured. As described above, more complex non-ideal and/or gas-specific

10 relationships between P_1, V_1, P_2, and V_2 is used for this calculation to model, for
example diatomic vs. monatomic gases.

After calculating the absolute static pressure at each point of
communication 32, 42 or 52, the static pressure differential from one point of
communication 32, 42 or 52, to another is determined by subtracting the

15 calculated absolute static pressures from one another. By dividing the static
pressure differential between two points of communication 32, 42 or 52, by the
distance between the two points of communication 32, 42 or 52,, an average static
pressure gradient between the two absolute static pressure sensors 20 is
determined. Using the physical properties of the working fluid in combination

20 with predetermined formulae for laminar flow in microfluidic channels with
various geometrical cross sections (see, for example, *Viscous Fluid Flow* by Frank
White, second edition, pp. 119-121) the flow rate can then be determined. For one
specific example, a microfluidic device with rectangular cross-section (a common
cross-section for micromachined microfluidic channels), the flow rate would be

25 determined by the following equation:

$$Q = \frac{4ba^3}{3\mu} \left(\frac{-\Delta P}{\Delta L} \right) \left[1 - \frac{192a}{\pi^5 b} \sum_{i=1,3,5,\ldots}^{\infty} \frac{\tanh(i\pi b / 2a)}{i^5} \right]$$

where Q is the flow rate of a working fluid of absolute viscosity μ through a
rectangular microfluidic device of width $2a$ and height $2b$, and ΔP is the

measured static pressure differential between two points of communication 32, 42, and/or 52 separated by a distance ΔL. Furthermore, by performing this calculation between several combinations of points of communication, the accuracy of the flow rate calculation is confirmed. This capability also lends itself

5   to analysis of microfluidic device clogging, localization of the region of failure of the microfluidic device 18. When the absolute static pressure downstream of a particular region drops while the upstream absolute static pressure remains constant, the source of the static pressure differential must be between the upstream and downstream absolute static pressure sensor.

10   FIG. 4 depicts a third embodiment of the absolute static pressure sensor 20 shown in FIG. 1, that measures absolute static pressure over several pressure ranges at its single first point of communication 30 with the microfluidic device 18. This is done by providing at least one additional fluid conducting channel in direct communication with the first fluid conducting channel and

15   providing an atmosphere by an additional selected gas in a sealed environment for such additional fluid conducting channel and an additional sensing mechanism disposed adjacent to the additional fluid conducting channel and wherein the additional selected gas environment associated with the additional fluid conducting channel has a different volume to cross-sectional area ratio than the

20   first selected gas environment in the first fluid conducting channel. By varying the ratio of the volume of the selected gas environments 36, 46 or 56 to the cross-sectional areas of their respective fluid conducting channels 34, 44 or 54, an absolute static pressure sensor 20 is created that can measure absolute static pressure over a variety of ranges, since the displacement of each interface 38, 48

25   or 58 is determined by the following relationship:

$$\Delta x = \frac{-\Delta V}{A} = \frac{\Delta P}{P_1} \frac{V_2}{A}$$

where Δx is the change in interface 38, 48 or 58 position, ΔV is the change in the volume of the corresponding selected gas environment 36, 46 or 56, and A is the cross-sectional area of the microfluidic channel. When the absolute static pressure

30   sensor 20 experiences small changes of the absolute static pressure from ambient

static pressure in the working fluid 30 at the first point of communication 32, the volume of the selected gas environment 36, 46 or 56 will show a correspondingly small change in volume.

In the embodiment depicted in FIG. 4, the displacement from equilibrium of the first fluid interface 38 would be less than the displacement of the second fluid interface 48, which in turn would be less than the displacement of the additional interface 58. This is magnified by using a larger additional selected gas environment 56, so that the change in volume ΔV is more evident, and/or by making the additional fluid conducting channel 54 narrower, so that the cross-sectional area A of the additional fluid conducting channel 54 decreases, increasing the linear displacement Δx of the additional interface. Thus, a narrow fluid conducting channel 34, 44 or 54 and a large selected gas environment 36, 46 or 56 are advantaged in accurately measuring a small change in absolute static pressure, which might be undetectable in a wider fluid conducting channel 34, 44 or 54 with a smaller selected gas environment 36, 46 or 56. However, the same sensor would not be able to measure large absolute static pressure changes, since the change in volume would compress the selected gas environment 36, 46 or 56 to a point where the interface 38, 48 or 58 position could no longer be measured by electrically interrogating the sensing mechanism 40, 50 or 60. By using additional sensors in communication with the microfluidic device 18 at the same point of communication 32, the higher absolute static pressure is measured on a coarser scale. Thus, an absolute static pressure sensor 20 combining a number of fluid conducting channels 34, 44 or 54 and selected gas environments 36, 46 or 56 with different volume to cross-sectional area ratios can measure absolute static pressure over a variety of pressure ranges at the same point of communication, thereby increasing the effective absolute static pressure range of the sensor.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	Printing apparatus
12	Ink reservoir
14	Drive electronics
16	Individually addressable printhead
18	Microfluidic device
20	Absolute static pressure sensor
22	Computer
24	Data
26	Transport mechanism
28	Receiver
30	Working fluid
32	First point of communication
34	First fluid conducting channel
36	First selected gas environment
38	First interface
40	First sensing mechanism
42	Second point of communication
44	Second fluid conducting channel
46	Second selected gas environment
48	Second interface
50	Second sensing mechanism
52	Additional point of communication
54	Additional fluid conducting channel
56	Additional selected gas environment
58	Additional interface
60	Additional sensing mechanism